Walking to Transit: Influence of Built Environment at Varying Distances

VARIOUS ENVIRONMENTAL INTERVENTIONS HAVE BEEN RECOMMENDED TO INCREASE NONMOTORIZED MODES OF TRAVEL IN THE LAST TWO DECADES. HOWEVER, IT IS UNCLEAR WHETHER IT IS EFFECTIVE TO TAKE A "ONE SIZE FITS ALL" APPROACH TO THESE INTERVENTIONS OR WHETHER THEY SHOULD VARY BASED ON DISTANCE TO THE DESTINATION.

BY PRAVEEN K. MAGHELAL, PH.D.

INTRODUCTION

Transportation plays a critical role in improving the livability of communities, because it is so closely tied to our daily activities. Public transit is particularly important because transit use improves community health by reducing negative environmental impacts such as air, water, and land pollution; it also reduces congestion resulting from extensive use of private automobiles for work- or non-work-related trips across both long and short distances (Stokes et al. 2008; Lachapelle and Frank 2009).

Travel demand studies have revealed that travel by personal vehicles is lower in neighborhoods with higher rates of walking (Ewing et al. 1994). Walkable neighborhoods also help increase the use of transit for all trips (Cervero and Radisch 1996). Since all transit trips involve some amount of walking, improving the built environment around transit facilities will help increase walking and eventually the activity level of the community. While the nature of the causal relationship between the built environment and physical activity is still being debated (Cervero 2002; Handy 2005), it is clear that there is an association between the built environment and transportation destinations at walkable distances (TRB 2005).

Recent studies have investigated the influence of the built environment on walking to transit and recommend various environmental interventions to increase walking (Schlossberg and Brown 2004; Besser and Dannenberg 2005; Brown and Werner 2007). However, it remains to be investigated whether the interventions should vary at different distances. This is important for two reasons. First, a distance-based analysis can provide in-depth knowledge about the specific interventions that can be retrofitted or designed to support walking for up to a mile, versus interventions that influence walking only up to a certain distance, say a quarter-mile. This can help transport planners propose effective transport improvement programs within the of available funds and avoid oversp on interventions that may not be eff in improving pedestrian accessibil stations. Second, when locations fo transit stations are being determine catchment area of the transit users p critical role. Estimates of the numb transit users who walk to a transit s will be more accurate if there is b understanding of the existing built ronment in the catchment area. Ther this study examines the built enviro of communities situated within qu mile and half-mile distances from D Area Rapid Transit (DART) stations las County, Texas, USA) and investi the role of the built environment on ing to transit stations. Such studi help propose interventions and p sensitive to the distance of walking from transit stations.

RESEARCH METHOD AND DATA

The present study investigate built environment's influence on wa to transit stations in communities a the light rail transit (LRT) stations i las County, Texas, USA. The DART serves 34 destinations with well-conn bus service within Dallas County, an average 59,292 riders per week 2005. DART has also encouraged v transit-oriented developments arou LRT stations and has attracted ex private investment to improve comm ties around stations. The city of Dalla North Central Texas Council of Go ment (NCTCOG), and DART ha sessed the built environment around t stations to create an inventory of da could increase accessibility to statio walking and biking. This study uses TOG spatial inventory data to exami built environment around the 20 D transit stations in operation in 2000

king to transit is calculated as a tage of transit users who walk to ART LRT stations. This informa- as gathered by the Dallas Area Transit System 2000 On-board mer Survey, which was adminis- y DART and NCTCOG. A total (of 1,026) weekday surveys and f 470) weekend surveys were col- and analyzed. Data from the week- rvey were used for the analysis. umber of transit users who walk RT stations was measured as the ing factor. The boarding factor aluated as the product of the re- factor and the vehicle factor. The se factor was calculated as the ratio stionnaires distributed to question- completed, and the vehicle factor lculated as the ratio of the number hicle trips for the stratum to the er of vehicles sampled in the stra- The boarding factor expands the leted interviews from sampled trips atum to represent total boarding by m. These 20 stations are located at s urban (CBD) and suburban set- (NC) and therefore provide enough variability in the built environment of the station area.

The spatial autocorrelation showed that the number of people walking to transit was random with respect to the stations. The Moran's I Index showed a value of -0.03 and a standard deviation of 0.3 Z score, using inverse distance of the spatial relationship. Another variable used in the analysis was the amount of parking available at the stations. This was identified as a confounding variable that could affect walking to stations (Loutzenheiser 1997).

A comprehensive list of independent variables of the built environment that influence walking was obtained by reviewing the existing pedestrian indices. They were then narrowed down to those that can be measured objectively in GIS and those that can be spatially derived (see Table 2).

STATISTICAL PROCEDURE

The total number of stations surveyed by NCTCOG and used for this study is 20. These form the total observations available. Statistical inferences cannot be validated with such a small sample. Nevertheless, the available sample can be treated as a pseudo or virtual population from which random samples could be generated using resampling methods such as bootstrapping or jackknifing. Random resampling with replacement in bootstrapping allows the development of an empirically normal distribution of a given sample's statistics (Efron and Tibshirani 1993). This avoids the requirement of large samples to determine the sampling distribution for significance testing in classical test theory.

Table 1. Characteristics of DART LRT stations.

ion	Corridor	Opened	Parking	Walk Percentage
kingbird	NC	December 1996	725	8.9
Lane	NC	December 1996	532	14.4
moreland	WOC	June 1996	668	22.8
etter	SOC	May 1998	400	22.9
End	CBD	June 1996	0	26.5
npton	WOC	June 1996	467	31.9
on Station	CBD	June 1996	0	33.5
nth	OC	June 1996	78	34.0
ois	SOC	June 1996	350	35.2
r/Vernon	WOC	June 1996	0	37.3
as Zoo	WOC	June 1996	0	39.4
st	SOC	May 1997	465	40.1
ers Lane	NC	December 1996	0	40.5
rd	CBD	June 1996	0	44.1
Paul	CBD	December 1996	0	46.0
d	CBD	December 1996	0	53.4
lars	OC	June 1996	0	59.6
rrell	SOC	June 1996	0	66.4
Hospital	SOC	May 1997	0	70.9
nv. Center	CBD	June 1996	0	82.1

RESULTS

Descriptive analyses of the built environment were performed at quarter-mile and half-mile distances from the DART stations. Mean, standard deviation (SD), and the difference in means were calculated for the 30 independent variables, for both quarter-mile and half-mile radii (see Table 3).The average sidewalk density at a quarter-mile distance was 1.34 (SD: 0.35), whereas the sidewalk density at a half-mile distance was 1.08 (SD: 0.31). Connectivity of sidewalks relative to the road was reported to be 20 percent and 30 percent higher at quarter-mile and half-mile distances, respectively. Built-environment measures such as average road width, length of road with median, road network, road with parking, and land-use mix were the same across the two distances.

Bootstrap Principal Component Analysis

Exploratory principal component analysis with Varimax rotation at the quarter-mile and half-mile distances revealed four principal components: (1) vehicle-oriented design, (2) density, (3) diversity, and (4) walking-oriented design. Reliability for each of these principal components was established by calculating the internal consistency using Cronbach's alpha based on standardized items (or Spearman-Brown corrected reliability). After the principal components were identified, bootstrap principal component analysis was performed individually for both distances. A thousand repetitions of the principal component analysis were performed using SPSS scripts. Factor coefficients that evolved from the repetitions were averaged to obtain the bootstrap

Table 2. Descriptive statistics of measured variables.

Variables	Quarter Mile Mean	Quarter Mile Std. Dev	Half Mile Mean	Half Mile Std. Dev	Mean Difference HMile - QMile
Sidewalk					
Sidewalk Density	1.34	0.35	1.08	0.31	-0.26
Sidewalk Connectivity	0.32	0.20	0.26	0.15	-0.06
Roads					
Road Connectivity	0.20	0.08	0.15	0.02	-0.05
Avg. Road Width	22.91	2.90	22.91	2.90	0.00
Road with Median	0.17	0.10	0.18	0.07	0.01
Road Network	2.26	0.72	2.26	0.72	0.00
Intersection					
Intersection Density	205.86	92.18	185.73	69.56	-20.13
Signalized Intersection	0.21	0.21	0.18	0.18	-0.03
Vehicle					
Road Speed	28.39	1.90	27.74	1.74	-0.64
Traffic Volume	14956.08	7541.13	14189.82	6690.50	-766.25
Pleasantness					
Tree Canopy	4.88	3.83	2.97	1.96	-1.91
Number of Street Lights	50.10	19.11	227.82	63.68	177.72
Sidewalk Cover	2.81	3.04	5.65	4.54	2.84
Density					
Population Density	3898.32	2788.84	4291.44	3106.36	393.12
Housing Density	1583.17	1311.13	1698.35	1395.80	115.17
Employment Density	3125.61	2193.82	3422.49	2359.51	296.88
Ethnic Density	2079.48	1608.39	2285.91	1755.24	206.43
Vehicles per HH	1.30	0.35	1.39	0.22	0.09
Median Income	17563.53	18798.29	38216.35	13394.33	20652.82
Safety					
Vehicular Safety	2.90	3.89	7.60	9.25	4.70
Personal Safety	687.13	590.75	561.94	393.57	-125.19
Destination Density					
Recreation	27.52	26.32	24.06	23.84	-3.46
Essential	57.83	62.61	44.56	28.51	-13.27
Administration	36.69	27.50	33.98	23.74	-2.71
Lateral Separation					
Road with Shoulder	0.36	0.21	0.41	0.12	0.05
Road with Parking	0.02	0.04	0.02	0.02	0.00
Land Use					
Land-use Mix	0.37	0.26	0.37	0.22	0.00
Average Parcel Area	23281.65	17940.81	40834.68	21005.90	17553.04
Residential Compactness	27.57	89.69	12.25	13.86	-15.32
Station Infrastructure					
Parking at Station	184.25	261.45	184.25	261.45	0.00
Walk Percent to Station	40.50	18.64	40.50	18.64	0.00

factor coefficients. Because the clu ing of variables in the bootstrap pri pal component analysis was identica that of the principal component an sis, the factor scores obtained from principal component analysis were for bootstrap regression analysis for b the quarter-mile and half-mile princ component analyses.

Bootstrap Regression

Two bootstrap regressions (with 1, repetitions) were performed for quar mile and half-mile distances from the tions. Income (measured as median come) and ethnic density were inclu in the equation as control variables (a Besser and Dannenberg 2005). The nu ber of users walking to transit stations be influenced by other modes of trave reach the station. Therefore, the numbe parking at each station was also include the analysis as a control variable.

In both models, indicators of walk to transit were tested for multicollin ity. Variables with a bivariate correla coefficient of more than 0.75 were cluded from further analysis. The o comes of the built environment variab were reported under each construc identified by the principal compon analysis at both quarter-mile and h mile distances.

Quarter-Mile Bootstrap Regression

After the test for the multicollinea of the variables, which is common in b environment analysis, 14 indicator walking to station were included in quarter-mile distance model (see Ta 3). The model was statistically signific (<0.001) and explained 90 percent of variance in walking to transit station.

One vehicle-oriented design v able (administrative destinations, -1.55, p<0.001), one walking-orien design variable (road shoulder, β = -0 p<0.001), and two density varia (sidewalk density. β = 0.88, p<0. and employment density, β = -2. p<0.05) showed a significant asso tion with walking to transit. Howe the availability of parking at the stat showed a negative association with w ing to transit that was significant at 0.10 level.

[Bootst]rap Regression for Half-Mile Distance

[Fi]fteen indicators of walking to transit [were] included in the half-mile model, [but] the test for multicollinearity elimi[nate]d other built-environment variables [(Tab]le 4). The half-mile model was sig[nifica]nt at the 0.05 ($p < 0.0001$) level and [accou]nted for 60.77 percent of variance [in wa]lking to transit stations.

[N]one of the vehicle-oriented design [vari]ables showed any significant associa[tion] with walking to transit. However, [the w]alking-oriented design variables did: [adm]inistrative destinations (β = -1.20, [p<0].05), road speed (β = -3.66, p<0.01), [vehi]cles per household (β = -0.75, p<0.01), [side]walk density (β = 4.64, p<0.001), [and] road shoulder (β = -0.58, p<0.001). [Ho]using density showed a negative as[soc]iation (β = -3.83, p<0.05), as did land [use] mix (β = -3.71, p<0.001).

[DI]SCUSSION

The present study models the walk[abi]lity to light rail stations for quarter-mile [an]d half-mile distances. Bootstrap regres[sio]n analysis at both quarter-mile and half-[m]ile distances reveals interesting results [th]at require further analysis. For instance, [ad]ministrative destinations such as post [of]fices, schools, and banks are negatively [as]sociated with walking to transit. This [m]ay be because these destinations gener[al]ly feature large parking lots to accommo[da]te vehicular traffic and are generally not [ar]chitecturally pleasing and therefore not [a]ttractive destinations for walkers. Further [id]iosyncratic analysis (both qualitative and [q]uantitative) is necessary to understand [b]etter this association.

Sidewalk density showed a positive as[s]ociation with walking to transit at both [d]istances. Therefore, increased walking [t]o transit has a significant positive as[s]ociation with the amount of sidewalk [p]er road length. A larger amount of [s]idewalk is therefore associated with in[c]reased walking, consistent with earlier [s]tudies. Other density indicators, such as employment and housing density, show a negative association with walk[in]g to transit. This is contrary to what other researchers have reported (Besser and Dannenberg 2005). In most studies, density variables are positively associated with walking for all purposes. Therefore, to investigate this relation further, we analyzed bivariate correlation of population, housing, and employment density with amount of parking at the station. The significant negative association indicated that locations with high density have stations with more parking spaces. This probably leads more transit users to drive to and park at stations, rather than walk to them. In order to confirm this assertion, we tested the mediation effect of parking on density.

Table 3. Quarter-mile bootstrap regression.

Variables	Std. Coeff.	Bootstrap Std. Err.	Z - Stat
Vehicle-Oriented Design			
Pedestrian Vehicular Accident	2.08	8.27	1.74
Administrative Destinations	-1.55*	9.54	-3.23
Recreational Destinations	0.58	3.28	0.64
Road Speed	-0.46	8.23	-0.54
Essential Destinations	0.35	1.12	0.47
Walking-Oriented Design			
Road Shoulder	-0.19*	5.05	-3.45
Road Connectivity	-1.65	9.66	-1.73
Sidewalk Cover	0.21	9.91	0.46
Density			
Sidewalk Density	0.88*	10.90	4.26
Intersection Density	-2.358	0.25	-1.92
Employment Density	-2.91***	0.01	-2.17
Residential Compactness	0.39	9.23	0.42
Diversity			
Road Width	-0.51	5.38	-0.60
Road Network	1.46	10.20	3.70
Control			
Ethnic Density	1.56	0.01	1.29
Median Income	-0.32	0.00	-0.30
Parking at station	-1.33	0.05	-1.89

**** <= 0.05; ** < =0.01; * <=0.001*
Number of obs = 20
Replications = 1000
Wald chi2(17) = 46.41
Prob > chi2 = 0.0001
R-squared = 0.9900
Adj R-squared = 0.9054
Root MSE = 5.7355

Mediating Effect on Walking to Transit

The role of density on walking to transit was investigated to see if any mediatory effect accounted for the unexpected negative coefficient of density variables at quarter- and half-mile distances. One plausible reason that a place with high density would report a low walking percentage is that individuals of that community use other modes of transportation to get to the transit station. Since driving is one of the major modes of transportation, measuring the mediating effect of driving on walking to transit could explain the role of density as reported by the bootstrap regression analysis. However, since the percent of transit users who drive to transit stations was not used for this analysis, the amount of parking at a station could be used as a proxy to measure the amount of driving to the station.

Table 4. Half-mile bootstrap regression.

Variables	Std. Coeff.	Bootstrap Std. Err.	Z - Stat
Vehicle-Oriented Design			
Traffic Volume	-2.36	0.01	-0.90
Street Light	0.32	0.55	0.13
Walking-Oriented Design			
Pedestrian Vehicular Accident	-0.40	19.95	-0.20
Residential Compactness	-0.27	16.67	-0.14
Administrative Destinations	-1.20***	34.53	-2.10
Road Speed	-3.66**	14.33	-2.74
Vehicles Per Household	-0.75**	23.65	-2.61
Sidewalk Density	4.64*	41.93	6.64
Road Shoulder	-0.58*	7.55	-11.64
Density			
Employment Density	1.44	29.19	1.36
Housing Density	-3.83***	39.21	-2.24
Diversity			
Road Width	-1.00	10.26	-0.63
Landuse Mix	-3.71*	31.80	-9.88
Average Parcel Size	2.33	0.00	1.56
Road Network	-1.76	27.45	-1.66
Control			
Ethnic Density	2.37	0.03	0.94
Median Income	2.76	0.00	1.08
Parking at station	-0.08	0.15	-0.04

**** <= 0.05; ** < =0.01; * <=0.001*
Number of obs = 20
Replications = 1000
Wald chi2(17) = 273.20
Prob > chi2 = 0.0000
R-squared = 0.9794
Adj R-squared = 0.6077
Root MSE = 11.6762

Also, the amount of parking at stations showed a significant negative correlation with walking to transit. Therefore, the mediating effect of amount of parking at the station on walking to transit was empirically tested using the procedure suggested by Baron and Kenny (1986) (see Figure 1).

The outcome variable (percent walking to transit) was regressed with the initial variable (population density) and the mediating variable (amount of parking at station). The significant regression coefficient of population density (β = -0.517, p<0.05) on walking to transit, when regressed again along with the mediating variable, had a regression coefficient (β = -0.231) that was not statistically significant (see Figure 1). This indicated that the amount of parking had a partial mediating effect on walking to transit. In the quarter-mile analysis, the amount of mediation or indirect effect was -0.286; in the half-mile analysis, the indirect effect was reported to be -0.292.

CONCLUSION

The results of the present study suggest that constructs of the built environment vary based on distance of walking. Recommended built environment variables should be analyzed for their effects at varying distances before policy recom- mendations are made to increase walking. The present study provides an important contribution by identifying the distance-based differences in the way built environment variables cluster to define physical constructs and the relationship of these variables with walking to transit. Future studies should be conducted to identify the specific distance-based interventions to increase walking in transit-oriented communities.

This study has important implications for transportation planning agencies and policymakers. First, built environment variables should not only be analyzed for their impact on walking alone but also for their role at specific distances of walking. Studies suggest that one mile is a reasonable walking distance (Canep 2007). Therefore, future studies should investigate the role of each environment correlate at every quarter-mile distance up to one mile. This will help identify the appropriate intervention at appropri distances and may reveal that a "one si fits all" intervention may not work increase walking in the community.

Second, an increase in density do not necessarily increase walking to tra sit. Improving other elements of t supporting environment that enco age walking and discourage driving c justify the increase in density in order increase walking to destinations such transit stations. Likewise, the influe of both individual and grouped la variables' influence on walking to tra needs to be investigated to identify s cific environmental interventions t can increase walking to transit. The diating effect of parking at stations population density indicates that p ning and transportation agencies sh make informed judgments as they locate funds for development of pe trian infrastructure. Stations with f parking spaces should be given pri for development of nonmotorized m of travel to stations.

Finally, with the current push b American Recovery and Reinvestmen of 2009 to improve transportation i structure, it is important to identi terventions that can support effectiv sustainable travel modes in commu

ıe nation. Therefore, studies that ıd the existing research on bus Cottrell 2007) and investigate the ıe built environment on bus use lominant mode of public trans- n) need to be conducted. This erefore calls for interventions to ified at specific distances that can ıvel efficient. ■

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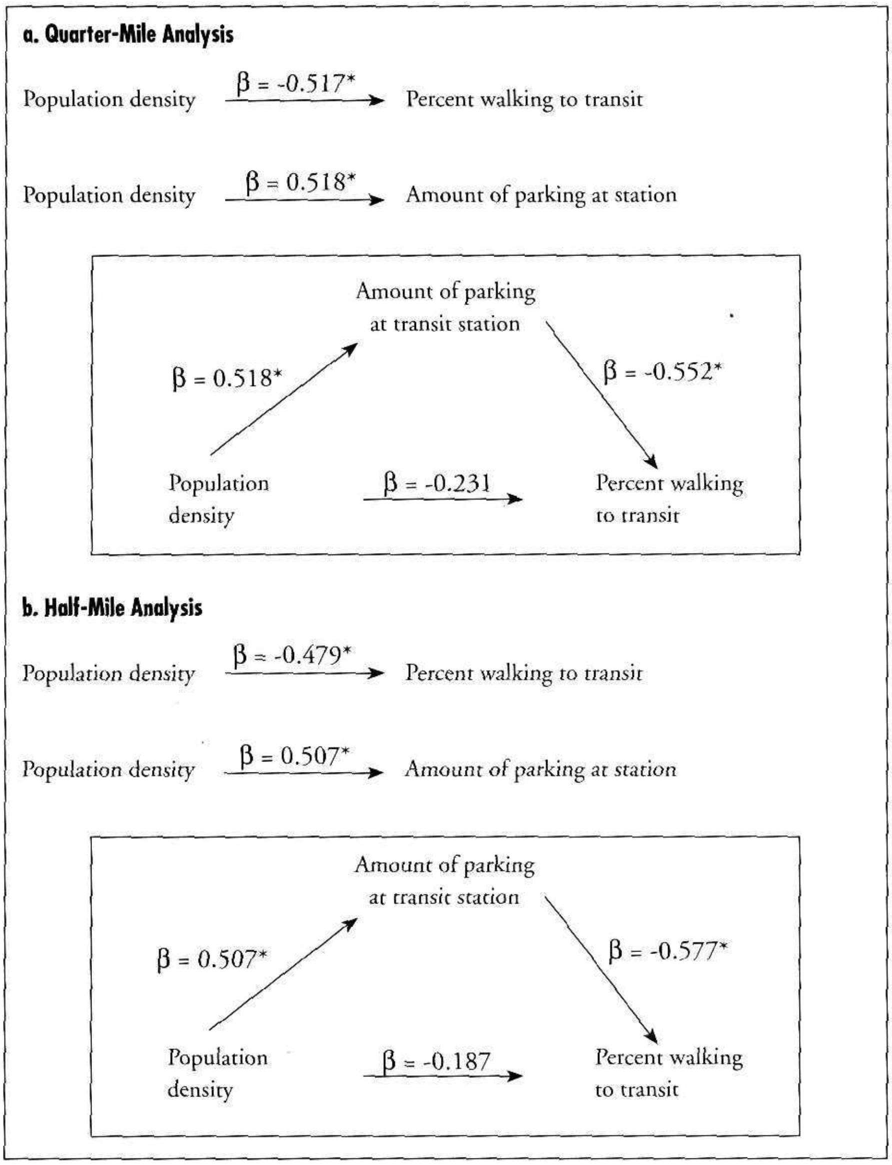

Figure 1. Mediating effect of amount of parking on walking to transit at (a) quarter- and (b) half-mile distance.

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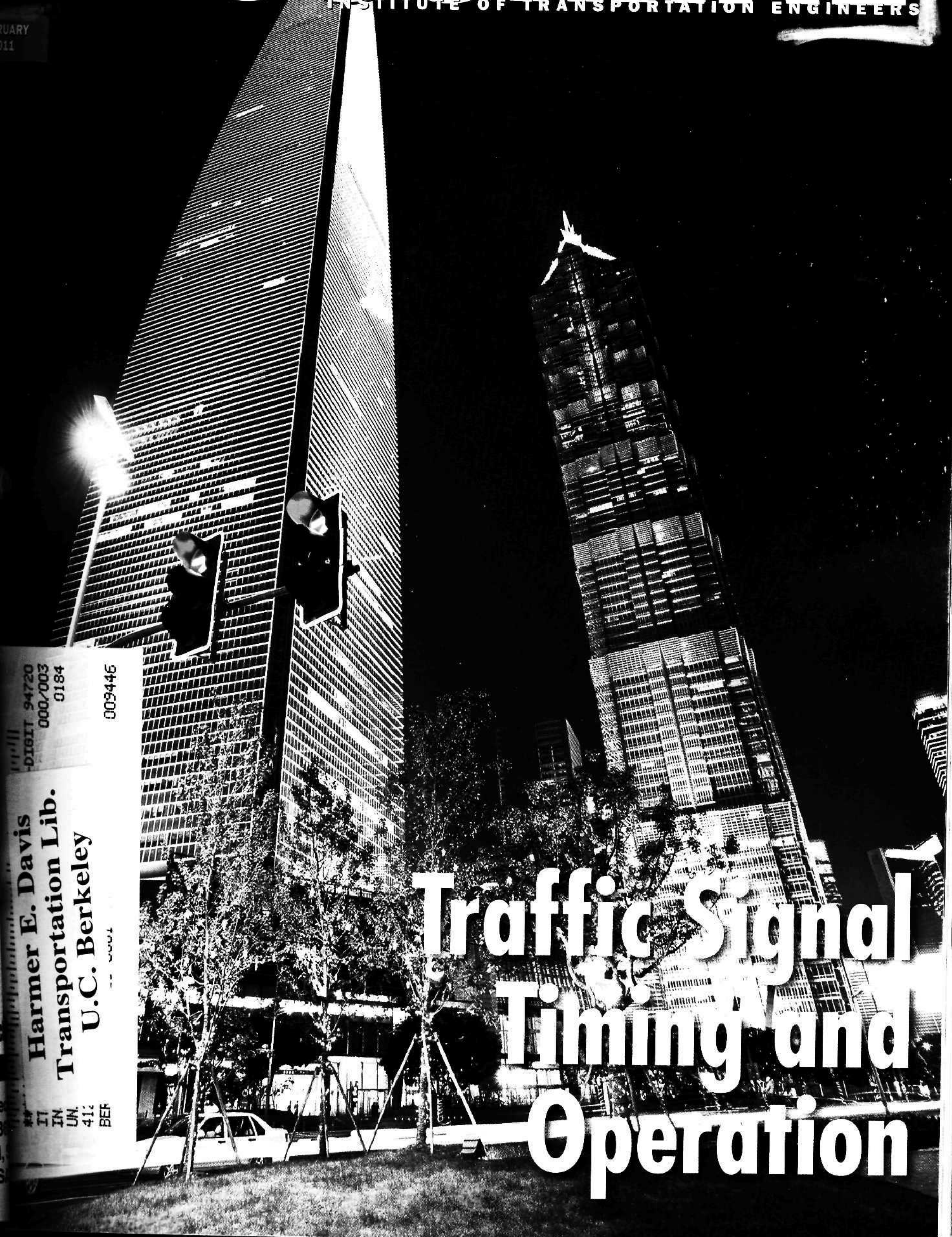

Traffic Signal Timing and Operation

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